UTILIZATION OF THE WORLD'S POTENTIAL WATER RESOURCES BY HYDROPOWER INSTALLATIONS

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At the threshold of the 21st century the use of water resources by constructing hydropower installations as one of the widespread types of generating electricity is faced with choosing ways of further development. Will the hydropower industry maintain the rate of development acquired during the present century that is coming to an end, or will it decrease to a certain minimum determined by local power and water-management interests? The answer to this question depends on global processes, such as the use of fossil fuel resources, conquering space, preservation of the human environment, etc.

For instance, the problem of the greenhouse effect, despite the different estimates of the rate of this process, will inevitably lead to the need to reduce the emission of greenhouse gases, substances, and heat not only by improving power production but also by limiting them.

Political, economic, and social factors also have a definite effect on the rate of development of the power industry, but their significance is secondary, since they govern temporal and local variations of power development. Of interest under these conditions is an assessment of world trends in hydropower development.

In recent years a number of factors affecting the scale of use of waterpower have appeared. The most essential are the properties of renewable energy sources and comparatively low cost of the electricity being generated. Precisely these factors can affect the scale of use of waterpower in Russia under conditions of an energy market.

The development of water resources on a large scale required the construction of numerous dams and the creation of reservoirs. By 1990 the number of dams constructed in the world exceeded 36,000, of which less than 0.1% has a height of more than 200 m and 78%, 15-30 m [9].

The total capacity of the reservoirs reached 5500 km^3 and the useful, 3660 km^3. Water was distributed among water users so: irrigation 70%, industry 23%, and water consumption 7%.

The capacity of hydropower installations by 1989 was 550 GW, by the start of 1991 it was 628 GW, and according to predictions it will increase to 750 GW by the year 2000. In connection with the high degree of utilization of the hydropower potential, in a number of countries the capacity of pumped-storage stations (PSSs) will continue to increase in the structure of generating capacities, approaching 100 GW.

Hydropower Potential. The periodically published data on the world theoretical, technical, and economic hydropower potential of rivers with respect to continents and individual countries are quite contradictory both in an absolute expression and in a relative comparison of these three estimates among themselves. Of unquestionable interest are the data published in [10]. It follows from their analysis (Table 1) that relative to the theoretical potential, estimated to be 35,000 TWh, the technical – 15,000 TWh – amounts to 42.8% and the economic – 5500 TWh – to 15.7%.

At the same time, according to detailed domestic calculations for countries that were in the USSR and were under quite diverse natural conditions, it was found that the technical potential is 63.1% of the theoretical without small rivers and 53.4% with small rivers, and the proportion of the economic potential is respectively equal to 32.8 and 27.8%. To speak to the point, consideration of small rivers for Russia, for example, increases the theoretical potential from 2395 to 2896 TWh, i.e., by 21%.

In certain published sources, particularly in [1], the world economic hydropower potential was estimated to be 9800 TWh, which is 4300 TWh or 78% greater than the indicated new data – 5500 TWh. Such a marked decrease can probably be explained by an increase of the cost of lands being expropriated and more stringent ecological requirements imposed when constructing hydropower installations.

Therefore, it seems that orientation toward the technical potential is the most objective assessment when comparing hydropower resources of continents, countries, and regions among themselves. This pertains also to comparative data on the degree of utilization of hydropower resources.

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TABLE 1. Hydropower Potential of the World, Continents and Certain Countries

Name of country		Hydropotential, TWh			Degree of utilization E_t, %
		theoretical E_{th}	technical E_t	economic E_e	
I. Europe (countries with E_t > 20 TWh)					
	Total	2623	1227	860	35,9
Including	Norway	550	(270)[1]	200	(44,8)
	Italy	340	150	65	23,4
	France	266	72[2]		(79,7)
	Sweden	200	(130)	95	(56,2)
	Spain	150	70	66	37,4
	Austria	150	75	54	43,3
	Switzerland	144	41	37	75,6
	Germany	120	27	20	72,2
	Yugoslavia	84	50		40,2
	Greece	84	25	16	
	Romania	70	40	17	27,5
	Finland	46	20	20	54,5
II. Former USSR (republics with E_2 > 20 TWh)					
	Total	3942[3]	2106[4]	1095	(11,1)
Including	Russia	2896[3]	1670	852	(10,0)
	Tadzhikistan	300	144	85	—
	Kazakhstan	199	62	27	—
	Georgia	159	68	32	—
	Kirgizia	142	73	48	—
	Uzbekistan	88	27	11	—
	Ukraine	45	21	17	—
III. Asia (countries with E_t >80 TWh)					
	Total	15 000	5000	1530	8,3
Including	China	5922	1923[2]	—	5,8
	Indonesia	3388	709[2]	(150)[5]	12,7
	India	2637	(750)[2]	600	(9,4)
	Japan	718	135[2]	114	71,0
	Turkey	433	216	122	10,7
	Malaysia	218	87	—	8,2
	Pakistan	150	(105)	70	(16,1)
IV. Africa (countries with E_t > 20 TWh)					
	Total	(3100)	1400	(1094)	3,6
Including	Zaire	—	530[6]	530[6]	1,1
	Cameroon	173	115	—	—
	Tunisia	150	150	140	—
	Angola	150	100	—	—
	Mozambique	—	72	—	—
	Nigeria	—	—	40	—
	Zambia	—	29	—	26,7
	Zimbabwe	23,6	20	19,3	17,6
V. North America					
	Total	2005	(1412)	766	(43,4)
Including	Canada	977	632	230	47
	USA	528[7]	(450)[5]	376	(64,7)
	Mexico	500	(330)[5]	160	(7,6)
VI. South and Central America (countries with E_t > 40 TWh)					
	Total	9000	4000	3000	8,4
Including	Brazil	3020	1195[6]	1117[6]	17,3
	Peru	1840	1092	412	1,1
	Colombia	1290	521	418	5,2
	Ecuador	818	188[2]	115	2,6
	Argentina	535	(450)	390	(4,0)
	Venezuela	335	277[6]	262[6]	13,4
	Chile	181	(150)	132	6,1
	Bolivia	178	126	50	
	Paraguay	51	(45)	40	5,3
VII. Australia and Oceania					
	Total	595	(250)	172	(15,2)
Including	Australia	264	(54)[2]	30	(27,4)
	New Guinea	175	(115)	98	(0,4)
	New Zealand	152	77	44	28,4
Total: world		35 000	15 000	5500	14,4

Notes. [1]In view of the absence of data in [10], everywhere in parentheses is given information from other sources or a rough estimate according to analogues. [2]The data on E_t are clearly underestimated compared with E_p and require checking. [3]Without small rivers, respectively 3338 and 2395 TWh. [4]In [10] is indicated 2190 TWh. [5]Approximate information requiring refinement. [6]The equality or closeness of the values of E_t and E_e indicated in [10] cause doubt. [7]According to other data, about 700 TWh.

It is admissible to make a comparison of the economic potential within countries, i.e., for individual streams, since in that case the conditions of comparability are satisfied with consideration of the characteristics of economic development of a particular country. In connection with this, the degree of utilization of hydropower resources (Table 1) is oriented precisely at this method of calculation, i.e., is given relative to the technical potential and, consequently, is lower than usually indicated in the literature in estimates on the basis of the economic potential.

As a result it turns out that only in Europe and North America is 35-45% of the technical potential used, and on the other continents it is used considerably less: 3.5-8.5% in Africa, Asia, and South and Central America and 15.2% in Australia and Oceania.

France, Switzerland, Germany, and Japan are distinguished by the highest degree of utilization (70%), about 65% is utilized in the USA, about 54-56% in Finland and Sweden, 47% of the technical potential is used in Canada, and on the whole the degree of utilization in the world, according to the data [10], does not exceed 15%.

Construction of Hydroelectric Stations. Increased interest in the construction of small hydroelectric stations (HESs) has recently been shown in a number of countries. In developed countries this interest is due to the high degree of utilization of the technical hydropower potential by large and medium HESs already constructed, and in such developing countries of Asia as China, India, Indonesia, and Malaysia and in Latin America as Brazil, Peru, and Bolivia by the presence of numerous small power consumers and lack of development of centralized power-supply systems.

The share of participation of small HESs in the energy balance can be judged by the examples of Sweden and countries of Latin America. In Sweden 1100 HESs in 1990 produced 63.5 TWh, including 740 small HESs (P_h = 1.5-10 MW) 2.5 TWh and mini-HESs (P_h = 0.1-1.5 MW) 1.0 TWh, i.e., their total share did not exceed 5.5%. In Latin American countries where the share of HESs is about 60%, small HESs accounted for 0.5%.

Evidently, as industry of various countries develop standard production units for small HESs, which will greatly increase the cost effectiveness of their use, construction will be carried out more actively and to a more weighty degree.

At present the construction of cascades of channel low-head multipurpose hydro developments is continuing in developed heavily populated European countries on such large rivers as the Danube, Rhone, and others. The matter of constructing the next hydro development of the cascade of 10 channel installations in the middle course of the Danube below Vienna is being discussed. Downstream, despite the refusal of Hungary to continue the construction of the Gabcikovo hydro development, Czechoslovakia, according to the latest data, intends to resume works for the purpose of completing them (readiness is estimated to be up to 95%). According to other data, the disputable matter of mutual obligations will by solved by the International Court at The Hague.

On the Paraná River, Argentina with Paraguay is completing the construction of the first phase of the 2.7-GW Yacyreta HES with 20 units (the second phase with another 10 units) and together with Brazil is beginning preparatory works on constructing the upstream step of the cascade, the 4.6-GW Corpus Christi HES with 32 units, it will become the world's largest channel-type hydrostation. The largest 9.5-m-diameter Kaplan turbines in countries of the Western Hemisphere are being installed at these HESs.

In China construction of the country's 2.7-GW channel-type Gezhuoba HES, where two unique Kaplan-type turbines with a record diameter of 11.3 m and capacity of 175.5 MW each (the other 19 units with turbines with 129 MW each) are installed, was completed. Upstream, preparations are being made to construct the Sang Hsia ("Three Gorges") HES, one of the world's largest, with a capacity in the first stage of 8-10 GW with the possibility of an increase to 20-25 GW. The country's largest, also a reservoir-type, Êrht'ang HES on the Yapong River with a unique 245-m-high arch dam and the country's largest mixed-flow turbines 6 × 50 MW will be carried out during 1991-1998.

As examples we can give a number of other channel- and reservoir-type HESs recently constructed and under construction not only on large rivers. At the same time, the construction of HESs unique in capacity has continued in the past 10-15 years both in developed and developing countries.

In the USA the capacity of one of the world's largest HESs, the Grand Coulee, was brought up to 9.7 GW. In Canada the first stage of constructing a cascade of three installations, Nos. 2, 3, and 4, with a total capacity of about 10.3 GW and annual production of 62.2 TWh (including the La Grande 2 HES with a capacity of more than 5.3 GW) on the La Grande River was completed. In the second stage of utilizing the hydropotential of the La Grande River basin, the total capacity of the installations will increase by 5.5 GW (including at the La Grande 2A under construction since 1987 – an additional 2.0 TW), and power production will increase by 20.9 TWh.

TABLE 2. Installed Capacity and Power Production of All Electric Power Stations and Share of Hydropower Installations (HESs and PSSs)

Name of country	Installed capacity, GW			Power production in 1990, TWh			Number of hours of use, P_{HESs}
	all stations, P_e	including HPIs, P_h	share of HPIs, %	all stations, P_e	including HPIs, P_h	share of HESs, %	
I. Europe (countries with P_e > 5 GW)							
Total	678,4	171,6	25,3	2810	477	17,0	2780
Germany	123,1	8,9	7,2	572	19,5	3,4	2190
France	103,4	24,7	23,9	420	57,4	13,7	2325
Great Britain	73,1	4,2	5,7	319	7,1	2,2	1690
Italy	56,5	18,8	33,2	217	35,1	16,2	1865
Spain	43,3	16,1	37,1	151	26,2	17,4	1625
Sweden	34,2	16,3	47,8	147	73,1	49,9	4485
Poland	30,7	1,9	6,0	136	3,3	2,4	1735
Norway	27,2	26,9	99,1	122	121	99,6	4500
Romania	23,9	5,6	24,4	64,3	11,0	17,1	1965
Czechoslovakia	20,7	2,9	14,2	89,3	4,7	5,3	1620
Holland	17,4	0,04	0,1	71,9	0,1	0,2	2500
Austria	16,8	10,9	64,9	50,4	32,5	64,5	2980
Yugoslavia	16,5	7,0	42,5	85,9	20,1	23,4	2870
Switzerland	16,3	12,4	75,8	55,8	31,0	55,5	2500
Belgium	14,1	1,4	9,9	70,2	0,27	0,4	1900
Finland	13,2	2,6	19,8	54,5	10,9	20,0	4190
Bulgaria	9,98	1,98	19,8	41,3	2,3	5,6	1160
Greece	8,51	2,41	28,3	35,0	2,0	5,7	890
Portugal	7,38	3,36	45,5	28,5	9,3	32,6	2735
Hungary	6,60	0,05	0,01	28,4	0,18	0,6	3710
II. Former USSR							
Total	333,0	64,1	19,2	1726	233	13,5	3635
Including Russia[2]	206,0	42,0	20,4	1068	167	15,6	3975
III. Asia (countries with P_e > 5 GW)							
Total	572,9	120,6	21,0	2572	413	16,1	3425
Japan	194,8	37,8	19,4	857	95,8	11,2	2535
China	98,6	30,1	30,5	618	111	17,9	3690
India	76,0	18,9	24,8	286	66,1	23,1	3230
South Korea	24,1	2,34	9,7	119	6,36	5,36	2720
Iran	17,6	1,8	10,3	56,0	6,6	11,8	3665
Turkey	16,3	6,76	41,5	57,5	23,1	40,2	3415
Indonesia	11,5	1,95	17,0	44,3	8,95	20,2	4510
Thailand	9,72	2,27	23,4	46,2	4,98	10,8	2195
North Korea	9,50	5,0	52,6	53,5	31,7	59,3	6340[1]
Iraq	9,00	0,15	1,7	29,2	0,61	2,09	4065
Pakistan	9,14	2,90	31,7	43,9	16,9	38,6	5830
Philippines	6,87	2,17	31,6	26,3	6,08	23,1	2800
Malaysia	5,04	1,46	28,9	24,7	7,11	28,7	4870
IV. Africa (countries with P_e > 1 GW)							
Total	72,7	19,3	26,6	315	50,0	15,7	2590
South Africa	25,9	1,58[2]	6,1	165	1,84	1,12	1165
Egypt	11,7	2,75	23,4	39,6	8,1	20,5	2945
Algeria	4,66	0,29	6,1	16,0	0,13	0,84	4485
Nigeria	4,04	1,90	47,0	9,94	2,21	22,3	1165
Zambia	2,44	2,24	92,2	7,77	7,73	99,5	3450
Zaire	2,83	2,77	97,9	6,15	6,00	97,5	2165

TABLE 2 (continued)

Name of country	Installed capacity, GW			Power production in 1990 TWh			Number of hours of use, P_{HESs}
	all stations, P_e	including HPIs, P_h	share of HPIs, %	all stations, P_e	including HPIs, P_h	share of HESs, %	
Morocco	2,36	0,63	26,5	9,63	1,22	12,7	1935
Mozambique	2,36	2,08	88,1	—	—	—	—
Zimbabwe	2,04	0,63	31,1	9,56	3,52	36,9	5585[1]
Ghana	1,19	1,07	90,3	5,29	5,23	99,0	4890
V. North America							
Total	908,3	157,3	17,3	3635	613	16,9	3895
USA	775	90,1	11,6	3031	291	9,6	3230
Canada	104	59,4	57	482	297	61,6	5000[1]
Mexico	29,3	7,8	26,8	122	252	20,6	3230
VI. Central and South America (countries with $P_e > 1$ GW)							
Total	134	83,2	62,0	485	338	69,7	4060
Including							
Central America	17,5	2,8	16,0	63,0	12,4	19,7	4430
Brazil	52,9	45,6	86,1	222	207	93,3	4540
Venezuela	18,6	7,91	42,4	61,0	37,2	61,1	4710
Argentina	17,1	6,50	37,9	50,9	18,1	35,6	2785
Colombia	9,41	7,20	76,5	36,0	27,2	75,6	3780
Paraguay	5,80	5,79	99,8	2,44	2,43	99,8	4140
Peru	4,14	2,40	57,9	13,8	10,5	75,8	4375
Chile	4,08	2,29	56,1	18,4	9,07	49,4	3960
Uruguay	1,68	1,20	71,1	7,37	6,37	86,4	5310[1]
Ecuador	1,66	0,9	54,1	6,33	4,97	78,6	4140
VII. Australia and Oceania							
Total	45,8	12,3	26,8	190	38,1	20,1	3100
Including							
Australia	36,8	7,3	19,8	155	14,8	9,6	2025
New Zealand	7,5	4,6	62,0	30,2	21,9	72,8	4760[1]
New Guinea	0,5	0,16	31,6	1,8	0,46	25,7	2875
Total in world	2745	628	22,9	11733	2162	18,4	3445

Notes. [1]Maximum number of hours on the continent or in the region. [2]Approximate data are given.

The world's largest Itaipu HES (Brazil–Paraguay) on the Parana River was recently put into operation at full capacity – 12.6 GW. In Venezuela, on the Caroni River, after completing radical reconstruction of the Guri HES, the world's second in capacity, 10.3 GW, construction of the Managua II HES with a capacity of more than 2.5 GW was launched [4]. Among the very large reservoir-type installations are also the Hingu HES under construction in Brazil with a capacity of 8 GW at full development (start-up of the first phase 6 × 500 MW is planned in 1994) and the Tucurui HES of the same such capacity, the first phase of which with 4 GW in 12 units with very large 8.35-m-diameter mixed-flow turbines was started up in 1985.

In Turkey, on the Euphrates River, construction of a similar hydro development with an earth dam and the country's largest Ataturk HES with a capacity of 2.4 GW in eight units was completed in 1991-1992. The Karakaya HES with a capacity of 1.8 GW in six units was constructed prior to this.

The total installed capacity of all electric power stations and their annual production as well as the share accounted for by HESs and PSSs are given for continents and a number of countries in Table 2, based mainly on the data in [10].

In the world there are a number of countries distinguished by active construction of hydropower installations. In Europe, Norway and France are distinguished by the greatest installed capacity of hydropower installations, about 25 and 27 GW, and in Sweden, Spain, and Italy from 16 to almost 19 GW. China and Japan are distinguished in Asia, from 30 to 38 GW, India is considerably inferior to them, up to 19 GW. In Africa only Mozambique, Zambia, Egypt, and Zaire have a capacity of HESs within 2-2.5 GW. The following countries occupy a special place in the world with respect to total installed capacity: Russia, about 42, Brazil, more than 45, Canada and the USA, respectively more than 59 and 90 GW (Table 2).

Of substantial interest is an analysis of the question of the character of the operating regimes of the hydropower installations (HPIs) by comparing the number of hours of use of their installed capacity. On the whole for the world it amounts to 3445 h, varying from 2590 h in Africa and 2780 h in Europe, which is explained by the small share of HPIs in the energy balance ($\sim 16\%$) with a large share of PSSs with a peak-load regime, to 4060 h in Central and South America, where HESs serve as the base of power supply (their share is 60-70%).

An intermediate position is occupied by Asia – 3425 h – and North America – about 3900 h – with a large share of PSSs in the USA and, conversely, with a unique base-load regime of HESs in Canada – 5000 h (a greater number of hours is noted only in North Korea, Pakistan, Zimbabwe, and Uruguay). The comparatively small number of hours in Asia (without countries that were in the USSR) is explained by the fact that Japan accounts for more than 23% of the capacity of all HPIs of the continent in the presence of a large number of PSSs in that country, which on the whole was responsible for the lower number of hours of use of HESs and PSS taken together – 2535 h. As for Russia, the number of hours of use in it is estimated to be substantially higher than in the former USSR, namely, 3975 versus 3635 h.

On the whole, despite the increased interest in developing the underutilized hydropotential of small rivers by constructing small HESs, the increase of the installed capacity of hydropower installations in developing countries as before is occurring mainly due the construction of large- and medium-capacity HESs, and in developed countries by an increase of peak-load capacity at highly flexible PSSs.

However, the factor of ecological safety can most substantially affect the rate of increase of hydropower capacities by constructing large and medium HESs. Only a fundamental rethinking of the role of ecological safety as a determining principle of planning HESs can preserve the significance of large multipurpose hydropower installations in the development of the hydropower industry [7].

Construction of Pumped-Storage Stations. Since the time of constructing the first PSS, Letten, with a capacity of 1 MW in Switzerland, 110 years have passed. Whereas in 1940 there were only 40 PSSs, in 1965 there were already 110 [5]. This process of active construction of PSSs that began 30-35 years ago is due to the fact that a number of developed countries to a considerable extent exhausted their economic hydropower potential under conditions of a continuing increase of peak loads. An important role is played by the fact that disturbances of ecological conditions are comparatively small in the construction of PSSs [6].

The number of PSS and their total as well as single capacities continued to increase further at a rapid rate, which is seen from the following data:

Years	1970	1978	1990
Number of PSSs	150	208	280
Their total capacity, GW	15	44	85.5
Average capacity of PSSs, MW	100	211	304

According to the latest data published in [10] and given in Table 3, by now PSSs are operating in 35 countries of the world. In 14 countries their total capacity does not exceed 1 GW (in Argentina and Norway it is close to it), in 10 it is within 1-1.8 GW, and in the other most developed 10 countries it exceeds 2.3 GW.

These 10 countries account for about 200 PSSs with a total capacity of 67.5 GW, which amounts to almost 80% of the capacity of all 280 operating PSSs. The first six countries enumerated in Table 3, which account for 170 PSS, or 60%, and their total capacity is 56.7 GW, i.e., more than 63%, are among those especially actively constructing PSSs. The USA and Japan stand out, in turn, among these countries, in each of which operate 38 PSSs, their capacity exceeds, respectively, 18 and 17 GW, and taken together amounts to more than 40% of the world's total capacity of PSSs.

TABLE 3. Distribution of PSSs Operating and Under Construction According to Countries

No.	Country	Operating			Under construction		Total	
		number	capacity, MW	production, GWh	number	capacity, MW	number	capacity, MW
1	USA	38	18 091	—	2	975	40	19 066
2	Japan	38	17 005	—	8	5480	46	22 485
3	Italy	16	6200	3450	1	1750	17	7950
4	Germany	33	5618	3496	—	—	33	5618
5	Spain	23	4900	3300	3	1320	26	6220
6	France	22	4900	3870	—	—	22	4900
7	Former USSR	3[1]	3025[1]	—	3[2]	4528[2]	6	7553
8	Austria	16	2815	3200	—	—	16	2815
9	Australia	6	2565	—	—	—	6	2565
10	Great Britain	3	2388	756	—	—	3	2388
11	Switzerland	18	1768	1640	1	5	19	1773
12	South Africa	3	1580	1841	—	—	3	1580
13	India	4	1389	—	3	1333	7	2722
14	Poland	3	1330	1902	1	750	4	2080
15	Czechoslovakia	5	1319	632	1	650	6	1969
16	Former Yugoslavia	4	1414	—	—	—	4	1414
17	Belgium	2	1200	625	—	—	2	1200
18	Luxembourg	1	1096	745	—	—	1	1096
19	South Korea	2	1032	1549	1	600	3	1632
20	China (Taiwan)	1	1000	1807	1	1600	2	2600
21	China	2	37	—	4	2350	6	2387
22	Norway	7	995	1235	1	50	8	1045
23	Argentina	2	974	520	—	—	2	974
24	Portugal	4	562	151	1	140	5	702
25	Sweden	3	400	607	—	—	3	400
26	Thailand	1	360	341	—	—	1	360
27	Greece	1	315	102	1	300	2	615
28	Philippines	1	300	73	—	—	1	300
29	Ireland	1	292	285	—	—	1	292
30	Brazil	4	191	—	—	—	4	191
31	Canada	1	186	92	—	—	1	186
32	Bulgaria	2	149	266	1	864	3	1013
33	Romania	6	84	—	—	—	6	84
34	Colombia	3	31	—	—	—	—	—
35	Chile	1	29	—	—	—	—	—
36	Iran	—	—	—	1	1000	1	1000
37	Vietnam	—	—	—	2	155	2	155
	Total	282[3]	85 540[3]	—	36	23 850	316	109 390

Notes. [1]Instead of the one Zagorsk PSS with the capacity divided into two phases 800 and 400 MW indicated in [1], the three first PSSs – Kiev, Zagorsk, and Kaisiadorys – were taken into account. [2]Three installations actually under construction – Tashlyk, Konstantinovka, and Dnestr – were conditionally included. [3]Approximately refined data are given in the text.

The data in Table 3 are corrected only in the part concerning the former USSR, actually being oriented at other sources, particularly [11]; it should be noted that the number and capacity of PSSs operating in the first six countries are substantially understated. This permits at present the consideration that the number of PSSs is ~300, and their total installed capacity reaches 95-100 GW.

In [10] there are 36 PSSs under construction, which is a clearly understated number, since it is known that such countries as Germany, France, Italy, and a number of others continue to actively construct PSS, and certain developing countries are beginning to master their construction. It can be assumed that by 2000 the number of PSSs in the world will increase to 340-350 and their total capacity will be ~120-125 GW.

As for the current state of construction of PSSs, it is necessary to note some characteristics of it. Along with the indicated trend of a systematic increase of the average capacity of PSSs, an increase of the single capacity of the units and striving to construct individual large installations, including HES-PSS, are occurring.

Evidence of this is that more than 40 PSSs with a capacity of more than 1 GW are being operated and constructed in the world, i.e., this category includes about 15% of their total number. A list of several largest such installations is given in Table 4.

TABLE 4. Largest PSSs in a Number of Countries and the World

Name of PSS and HES-PSS	Country	Year of start-up	Head, m	Capacity, MW	Units
Bass County[1]	USA	1985	393	2520	6×420[2]
Dnestr[1]	Moldavia (Ukraine)	Under construction	139	2268	7×324
Ludington	USA	1973	120	1938	6×323
Tashlyk[1]	Ukraine	Under construction	87 80	1860[3]	6×150 4×240
Dinerwig	Great Britain	1981	545	1800	6×300
Gran Maison	France	1982	972	1800[3]	12×150
Mingtang	China (Taiwan)	1993	401	1650	6×275
Kaisiadorys	Lithuania	1990	112	1600[4]	8×200
Tamet III[1]	Australia	1972	151	1500[3]	6×250[2]
Ciota Piastra	Italy	1974	1070	1430	8×160[5]
Shintokasegawa	Japan	1979	265	1280	4×320
Ohkavachi	Japan	1992	407	1280	4×320
Zagorsk[1]	Russia	1988	115	1200[4]	6×200
Dreikensberg	South Africa	1982	467	1200	4×300
Vianden I and II[1]	Luxembourg	1964	294	1115	9×100[6]
Markersbach	Germany	1979	307	1092	6×182
Co-Trois Pon	Belgium	1979	260	1050	3×205[7]
Sia Bishe	Iran	Under construction	480	1000	4×250

Notes. [1]Installations of the semiunderground type, the others – underground. [2]According to the available data, the maximum capacity is 450 and 280 MW. [3]HES-PSSs at which are installed respectively four and three "direct" units. [4]With full development. [5]Another 150-MW unit operates at a fall of 990 m. [6]A tenth 150-MW unit was installed in a second semiunderground powerhouse in 1973. [7]The first three units with a capacity of 145 MW each were put into operation in 1969.

Thus a single capacity of the units of 300-400 MW is becoming common, which is confirmed also by a number of other examples, the maximum capacity has reached 420-450 MW. Variants of units with a capacity of 660-700 MW are being considered in the designs of the Rudlen (France) and Bremm (Germany) PSSs [5].

As for the prospects of constructing PSSs as a whole, some countries are devoting great attention to them: in Japan 440 sites have been inspected, the capacity of the installations at which is 329 GW [10], in the USA respectively 34 and 20 GW, in the former USSR 150 and 60 GW, etc. A planned reserve of 2.0-3.0 GW is provided for, in particular, in Austria, Mexico, Netherlands, Poland, etc.

CONCLUSIONS

1. A comparable evaluation of hydropower resources for continents and countries should be made on the basis of the technical hydropower potential and not the economic, which depends to a greater extent on the specific economic development for each country at a given time.

2. Works on developing hydro resources are being actively carried out in a number of developed and developing countries by constructing small HESs, but the main role in their development as before is played by the construction of large and medium HESs.

3. Due to the active construction of PSSs in a number of countries, the number of hours of use of the installed capacity has a clear tendency toward a decrease, on the whole in the world it was 3445 h by 1991.

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